At major airports in several countries, the use of high-capacity aircraft and improved air traffic control systems has emphasized the constraints imposed on providing increased landside capacity. In some cases, adjacent development has prevented further expansion of passenger terminal facilities and contributed to the decision to build an additional airport to serve the same metropolitan area. This paper analyzes the airport landside functions and their relations and argues the need to assign priorities to each airport function in terms of access to the runway system. Lower priority uses should be assigned to remote areas of the airfield so that higher priority uses might expand into the vacated land close to the runways. Thus, land area is the fundamental factor in determining landside capacity. Where land is constrained, as in many metropolitan airports, effective expansion and more efficient use of the airport land area could be achieved through the use of remote and off-site land for certain functions that do not require access to the runway system.

The capacity of landside facilities constrains the ability of many metropolitan airports to meet air traffic demands. In many cases, there is little or no room for landside expansion, and airport authorities are faced with the problem of either finding a new airport site or adapting their operations to maximize landside capacity.

This problem of landside capacity is relatively new in terms of the evolution of major world airports. For many years after World War II, the principal constraints on airport capacity were to be found on the airside. Now, with larger aircraft, improved air traffic control procedures, and improved aircraft control systems, airside capacity is becoming less critical than the constraints imposed on the landside.

The importance of landside capacity has been demonstrated at a number of major world airports, including London (Heathrow)
and New York (Kennedy). It has also been a constraint at Toronto International Airport at Malton, where the development of the passenger terminals in the existing landside area has been constrained by major highways and air cargo and maintenance facilities. The latter example illustrates the need for independent expansion in each area of a major airport.

In Canada, we have had to deal with the need for additional airport capacity by developing new airport sites at Mirabel for Montreal and at Pickering for Toronto. In the case of Mirabel, we were able to acquire some 324 km$^2$ in 1969 for the airport as well as all the adjacent land that could be exposed to noise from flight operations. This ensured that future developments would be compatible with the effects of operations. There was some public debate at that time regarding the new airport, but this debate centered primarily on the choice of location rather than on the need for the new airport.

More recently, in Toronto, we are assembling some 72.9 km$^2$ of land for a new international airport. In this case, provincial and local government zoning regulations will be employed to protect the airport and adjacent future developments. However, we have encountered considerable public debate over the new airport, particularly concerning the need for a second airport. In the past year an airport inquiry commission has examined this issue of need and, following strict judicial procedures, has concluded that a second airport is needed for Toronto and that its most appropriate role would be for international traffic. On February 20, 1975, the Government of Canada announced its decision to proceed with the design and construction of international facilities at the Pickering site.

The sites in both Montreal and Toronto are within 48 km of the urban center and can be well connected to all parts of the region. Not all metropolitan areas are in the fortunate position of being able to find sites for new airports to so conveniently serve the traffic. In both London and New York, there have been considerable public debate and opposition to the development of new airport facilities. Given an increasingly sophisticated public and the concerns with the social and environmental impact of growth, the development of new airports in metropolitan areas will become more difficult and time-consuming, demanding the application of new ways and means for increasing the capacity of existing airports. It is clear that we are most unlikely to ever build third major airports in Montreal and Toronto, and it is interesting to note that the Paris Airport Authority changed its policy from seeking another airport site to provide capacity once De Gaulle Airport becomes saturated to finding other solutions.

Thus, the constraints on airport capacity will be found more and more on the landside in major metropolitan airports rather than on the airside. I believe that the problems of landside capacity are manageable to a significant extent and that our search for solutions may lead us to find better ways of serving air travelers. The landside capacity problem could indeed be an opportunity. This is the challenge that we are addressing in the design of airports in Canada and overseas.

**SIX LEVELS OF CONSIDERATION**

The airport system should be examined in terms of 6 levels of consideration:

1. System of airports serving the metropolitan area;
2. Each airport and its environs, including access and servicing systems;
3. The airport and its basic elements, such as passenger terminal area;
4. Individual functions included in each basic airport element;
5. Layout of the processing facilities associated with each function; and
6. Individual processing facilities.

**Metropolitan Airport System**

Level 1 covers all airports in the vicinity of the metropolitan area including military and civil aviation facilities, airports serving international, continental, and domestic
traffic, STOL-ports, and general aviation and industrial airports. Level 1 is concerned with the roles of each of the airports in the system and the associated airspace system. Important aspects of the airport system include the capacity of airports in the system, their convenience, their social and environmental impact, and their development and operating costs. Of particular interest for the subject matter of this paper is the total landside capacity of the airports in the system.

Each Airport and Its Environs

Level 2 is concerned with the traffic assigned to a given airport, the associated airport access and passenger-handling system, other supporting infrastructures such as water and sewer services, and the environment and development in the vicinity of the airport. In the context of this paper, the essential level 2 considerations focus on the ability of the airport access and servicing systems to meet landside demands generated by the airport operations. For example, commuter traffic loads on airport access roads may be more of a limiting factor in terms of road access capacity than the roads within the airport itself.

The Airport and Its Elements

The considerations at level 3 center around the allocation of land to the basic airport elements including the runway-taxi system, the connections to the airport access system, the location of access corridors on the airport site, the location of air cargo and aircraft maintenance facilities, the location of other elements such as airport support facilities, and the location and area of land for the development of passenger terminal facilities. From the standpoint of landside capacity, the principal elements of interest at this level are the passenger terminal area, the air cargo area, and airport-oriented industries including their associated connections to the airport access system by rail, road, and marine modes of transport.

Function of Each Airport Element

Each of the elements identified at level 3 comprises a number of basic functions. For example, the connections to the airport access system include airport roads, parking facilities, rapid transit and railway routes and stations, parking, and servicing facilities for buses, taxis, and rental cars. Similarly, the passenger terminal area comprises a number of functional areas including the terminal apron, the terminal building, the apron service road, curb and parking facilities, transit stops, and terminal utilities and services. In terms of landside capacity, the main functions of interest are the landside functions of the passenger terminal (including the aircraft apron), air cargo, airport-oriented industries, and other airport elements that generate significant landside demands. It could be argued that the apron is part of the airside taxiway and runway system. Although the apron does affect taxiway patterns and sometimes capacity, I believe it to be fundamentally related to aircraft turnaround and passenger, baggage, and cargo handling and therefore primarily a landside function.

Processing Facilities for Each Function

Level 5 is concerned with the internal layout of each functional area. For example, the passenger terminal structure comprises several types of processing facilities including enplaning and deplaning curbs; short-term and long-term parking facilities; enplaning and deplaning transit platforms; ticketing facilities; baggage check-in; pre-clearance inspections (immigration, customs); security check; hold rooms; aircraft loading bridges and vehicles; deplaning inspection lines (immigration, customs, health,
agriculture); baggage claim; baggage security check (to minimize theft); and passenger services including concessions, information systems, telephones, waiting areas, and nurseries.

The provision and interrelations of these basic processing areas establish the landside capacity of each functional area. For example, because of the terminal layout, certain processing facilities may not be capable of expansion because of the juxtaposition of other processing facilities. This type of constraint could inhibit landside operations at an airport terminal.

Each Processing Facility

In turn, the capacity of each processing facility is dependent on the layout of the individual processors in that facility. For example, the layout or use of curb facilities may not be compatible with the types of demands that are placed on that facility. For instance, conflicts may occur between the different types of traffic using the curb and the storage of rent-a-cars at the curb and thus reduce curbside capacity for serving other types of traffic.

Evolving Issues at Each Level of Consideration

There are obviously direct relations among the 6 levels of consideration. Clearly, the requirements of the airport access system (a level 2 consideration) should form part of the considerations supporting decisions on the assignment of traffic to the airports (a level 1 consideration). In turn, the landside capacity of each airport is dependent on the arrangement of the basic airport elements, a level 3 consideration.

As shown in Figure 1, landside demands are created by decisions that are made in descending order from level 1 through level 6; decisions at level 1 affect demands at level 2, and similarly level 2 decisions affect demands at level 3 and so on.

In terms of the supply side of the equation, the reverse order applies. For example, the layout of the individual processors in each processing facility affects the capacity of each functional area. Thus, the layout of each baggage claim device (a level 6 consideration) determines the capacity of the baggage claim area (a level 5 consideration).

Figure 1. Demand-capacity relations at 6 levels of consideration.
Similarly, the landside capacity of the metropolitan airport system is determined by
the landside capacity of each individual airport and its environs; level 1 capacity is
established by the sum of the level 2 parts. This demand-supply relation is funda­
tmental to an understanding of the evolving issues in terms of landside capacity at each
level of consideration as discussed below.

Metropolitan Airport System

The principal issues at this level of consideration are as follows:

1. How many airports are required to serve the diverse aviation needs of the met­
ropolitan area and its hinterland?
2. What types of civil aviation facilities and operations are appropriate to the air­
port system, given the range of existing and potential needs?
3. Can some of the requirements for these facilities be reduced by promoting other
modes of transportation, e.g., high-speed rail services, or by allowing certain air
traffic sectors to be served by other metropolitan areas? (Basically this issue centers
around the validity of existing and anticipated demands.)
4. How can the overall impact of the airport system in the metropolitan area be
best managed? How can aircraft noise be controlled and made compatible with existing
and potential future land uses?

A number of approaches can be considered. In Los Angeles, for example, satellite
airports have been developed to divert some traffic sectors away from the international
airport. Alternatively, a new airport facility is being developed in Toronto to divert
some international traffic from the existing international airport. Consideration was
also given to the possible future role of Metroports or STOL-ports in Toronto, and the
plans have flexibility to accommodate such developments. In particular, plans for a
possible STOL-port near downtown Toronto have received some consideration, and a
system of smaller airports is being designed to serve the centers of southwestern
Ontario.

The issues at level 1 are fundamental to any aviation program in large metropolitan
areas. Citizen groups are becoming more and more aware of these types of issues,
and it was necessary in Toronto to develop comprehensive and accurate technical in­
formation regarding the alternatives at the metropolitan scale. Such information should
be required in any case, but the degree of sophisticated public involvement now requires
that all alternatives be well examined and the work well documented.

Each Airport and Its Environs

The issues at level 2 are of major concern to airport managers around the world.
These issues relate to the problems of aircraft noise on the approaches to runways,
airport curfews, congestion on the major highway routes to airports, and the encroach­
ment of various types of land use in the areas surrounding the airport.

Many metropolitan airports were established in the 1930s and 1940s. These air­
ports were often located at some distance from built-up areas, and the land areas that
were acquired for these airports appeared at that time to be quite generous, in the
order of 4.05 to 12.15 km². Today, low-density growth in metropolitan areas has sur­
rounded these airports, thus creating the noise and access problems referred to earlier.
Moreover, the size of the airport cannot be expanded significantly because of the value
of and development on the adjacent lands and the social relocation that land acquisition
would involve. These land values and developments impose constraints on the location
of certain airport and airport access facilities. For instance, runway locations are
constrained by noise considerations, and access routes on the periphery of the airport
are constrained by local development and traffic demands.
The issues that are emerging at level 2, in turn, affect the basic arrangement of land use within the airport itself. For example, the growth of air traffic and the introduction of wide-bodied aircraft have created a need to expand passenger terminal facilities. At many airports, however, the area for terminal development has been confined by runways, air cargo and aircraft maintenance facilities, and major highways. It has been necessary at some airports, such as at London (Heathrow), to relocate some airport land uses to other parts of the airport to provide space for terminal expansion. A similar situation also developed at New York (Kennedy) Airport where the Port Authority of New York and New Jersey investigated the feasibility of developing Jamaica Bay in order to expand the capacity of Kennedy Airport.

The problems of passenger terminal area expansion will become common in the near future as the capacity of existing runway systems is increased through the use of larger aircraft and better control systems and the corresponding demands on the landside intensify. To relocate certain elements to provide space for terminal expansion requires that priorities be assigned among the competing airport land uses in terms of accessibility to the runway system. This assignment of priorities has major implications in relation to the level of service that is offered to travelers, the costs that are incurred by the airlines and other operators, the airport authorities, and the associated impacts on access and servicing systems.

At present, at least 1515 m are required between parallel runways in order to permit simultaneous, independent, instrument flight rule operations on each runway. In the future, it is possible that this minimum separation may be reduced to 1060 m. However, the advantages of this potential future development may be offset entirely by the land requirements for access roads to the passenger terminals. For example, a common airport layout would feature a road corridor feeding traffic to the terminals from 2 major freeway approaches. The merging of these traffic flows and the sorting of the combined flows by terminal, enplaning and deplaning levels, involve space-consuming roadway configurations. We are all familiar with the complex road systems on the approaches to most major metropolitan airport terminals; in fact, the distance requirements for merging and diverging traffic flows are in evidence in the approach road configuration to Tampa Airport. Thus, plans for new airports, such as Dallas-Fort Worth, Paris (De Gaulle), and Montreal (Mirabel), all show separation of the runways wider than the minimum of 1515 m and certainly more than 1060 m to accommodate landside facilities. But even in these major airports, all ground facilities are located optimally not for their own individual operations but for the entire airport operation. Priorities are thus assigned.

In summary, the emerging problems at level 3 have major implications in terms of the land allocation to the basic functions at airports. Accordingly, each land use must be assigned priority in terms of the importance of its accessibility to the runway system and the adjacent access systems. As high priority items require land for expansion, certain uses must be relocated to airport areas that are less accessible to the runway system and that may have irregular shapes because of their location around the periphery of the airport.

The natural outgrowth of this type of approach, which is now beginning to be considered, is then to assign priorities in terms of which elements should be located on-site and which can be located off-site. For example, linking off-site passenger terminals by rapid transit on a separate right-of-way to the airport terminal could reduce land areas required for car parking and buildings and thus increase the landside capacity of the passenger terminal area. Similarly, cargo warehousing and pickup from the groundside could be located off-site with delivery to a cargo-processing terminal or loading dock at the airport. Both of these examples have the effect of adding to the supply of airport land by the use of other land areas in the metropolitan region.
Function of Each Airport Element

The major level 4 issue relates to the functional plans for each airport area, such as the passenger terminal area and the areas for air cargo, airport support, aircraft maintenance, and other land uses. The dimensions that must be accommodated by these functional plans are determined by the decisions that are made at levels 1, 2, and 3, in particular, the assignment of priority in terms of accessibility to the runway and accessibility to the airport itself (off-site locations versus on-site locations). The ability of the functional plan to meet these established demands is dependent on the capacities that can be provided at level 5 and, in turn, at level 6.

To examine the functional planning for passenger terminal facilities in terms of the interaction of off-site and on-site facilities is of interest at this point. Figure 2 shows 4 basic options with respect to the types of processes that could be located at off-site passenger terminals. It is assumed that a separate transitway, such as a busway or rapid transit line, would provide nonstop service between the airport terminal and the off-site terminals in this example. If the off-site terminal is used only for assembly and distribution of passengers, the facilities off-site would be quite modest in scale and the major facilities would still be provided at the airport terminal. The major impact under this type of approach is on the road and parking facilities at the airport, although these may have already been developed to their maximum capacity. The use of off-site terminals for assembly of passengers would then add to the landside capacity by the use of a rapid transit service to add to the airport access capacity.

At the other extreme, a comprehensive range of passenger processes could be provided off-site including baggage check-in and claim, ticketing, and seat selection. This type of service could require some technological advances, but computer reservation technology has made seat selection quite feasible in off-site locations. Not until a few years ago could seat selection be accomplished at the hold room. In the case with comprehensive processing off-site, the facility requirements at the airport could be minimized and major terminal facilities would be required at the off-site locations. A major advantage of this type of strategy is that well-wisher and greeter facilities could be located almost entirely off-site. This approach has major implications in terms of well-wisher and greeter time (Figure 3) and system costs (Figure 4), but could have limited impact in terms of passenger time (Figure 5).

These graphs were developed during the off-site terminal research that we undertook for the Toronto Area Airports Project to determine whether off-site terminals would present any advantages in terms of overall system costs and levels of service for different assumed levels of airport transit usage. The fundamental conclusions were that off-site processing could make transit access to the airport attractive; that the level of service for many passengers could be equal to or better than access by road; and that, if greeters and well-wishers would stay at the off-site terminals, considerable time and cost could be saved. The functional division of elements has been said to have a fundamental effect on the ability of the facility to expand to accommodate technological change and differential growth of its elements. Just as independent expansion is required at level 3, so is it necessary at level 4.

Figure 6 shows the evolution of passenger terminal concepts from the first generation of small terminals through the larger walking access terminals of the second generation to the major terminals with airside transit systems for access to the aircraft from the terminal building of the third generation. Table 1 indicates the suitability of each approach (centralized and decentralized terminals and the first, second, or third generation) to given airport situations and traffic levels.

Processing Facilities for Each Function

The main issues of level 5 relate to changing operational requirements that are emerging with the growth of air traffic. During the past 5 years we have noted 2 major requirements in terms of passenger processing: the enplaning security check as a result of hijacking incidents and the deplaning baggage claim check as a result of baggage
Figure 2. Basic options for off-site passenger terminals.

Figure 3. Well-wisher and greeter times with off-site terminals.
Figure 4. Airport system costs with off-site terminals.

Figure 5. Passenger times with off-site terminals.
Figure 6. Evolution of terminals.

Table 1. Characteristics of large terminals.

<table>
<thead>
<tr>
<th>Terminal Type</th>
<th>Short Walking Distances</th>
<th>Efficient Use</th>
<th>Flexibility to Accommodate Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second generation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finger</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Ring</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Unit</td>
<td>Very good</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Third generation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satellite</td>
<td>Good</td>
<td>Good</td>
<td>Very good</td>
</tr>
<tr>
<td>Unitized</td>
<td>Very good</td>
<td>Very good</td>
<td>Very good</td>
</tr>
</tbody>
</table>
thefts. In some cases, the layout of facilities has enabled these new processes to be accommodated without difficulty as, for example, at Chicago (O'Hare) Airport, where security procedures were quite feasible because of the centralized design of the passenger terminal. The decentralized facilities at Dallas-Fort Worth Airport were less compatible for accommodating enplaning security checks. Similarly, at Washington (Dulles) Airport it has been necessary to introduce the security check at the entrance to the mobile lounges and, in fact, to use these lounges as hold rooms.

Again, the possible introduction of off-site terminals will affect the layout of individual processing systems. In particular, the baggage-handling systems will be affected should baggage check and claim be offered at the off-site terminals.

Each Processing Facility

As indicated earlier, the ability to provide capacity begins with the layout of each individual processor, and landside capacity is established from this process at level 6 through to level 1. The basic issue at level 6 is how to best meet the demand that is imposed by the decisions at the other levels. A knowledge of the operating experience with different layouts of a processor is essential to ensure effective use of available space to meet demands. A few years ago, we worked with the management of Toronto International Airport to identify ways of increasing capacity by means of operational measures in order to meet the Christmas peak-period demands. This was prior to the opening of the second passenger terminal at the airport. As a result of this work we were able to create a major increase in curb capacity by changing curb layout with the introduction of a second parallel curb.

Another example of the interrelation of operations and processor layout is the streamlining of inspection services, which has been achieved in Canada, the United States, France, and other countries. In Canada, the inspection of arriving passengers was expedited by establishing a primary inspection line, at which all passengers were quickly screened, and the use of a secondary inspection line, at which some passengers were given more detailed inspection and received declaration forms. This approach has greatly improved the level of service experienced by arriving passengers while meeting the cost-effectiveness objectives of the federal departments involved. This reorganization of inspection services, which cuts across 4 federal departments (health, agriculture, immigration, and national revenue), has had a direct effect on the layout of the associated facilities in the airport terminal buildings.

LAND IS FUNDAMENTAL FACTOR

We have discussed the implications of requirements for additional landside capacity on the roles of individual airports in the metropolitan airport system, the assignment of priorities to basic airport land uses in terms of their accessibility to the runway system, and the potential role of off-site facilities in increasing landside capacity by increasing the supply of land for airport purposes.

Clearly, landside capacity of an airport is directly related to the supply of land. Additional landside capacity can be provided if the land is available. In Toronto and Montreal we have been able to add to the total airport system capacity by adding more land in the form of new airports. This course of action may be less feasible in other metropolitan areas, such as London and New York, where land is constrained. Increased demands lead first to the reallocation of airport lands and second to the development of off-site facilities in order to realize additional landside capacity.

Recognizing that land is the fundamental factor that establishes landside capacity, we can make 2 corollary statements:

1. The planning of new airports should provide for the acquisition of more land than is estimated to be required based on forecasts for the foreseeable future; and
2. The planning for all airports should be aimed at making maximum use of the
land available at each site and, to the extent possible, the use of remote and off-site land to meet future requirements.

Given this context, the planning of landside facilities can proceed as follows:

1. Priorities must be assigned to airport land uses in terms of their relative proximity to the runways;
2. The airport land should be allocated on the basis of these priorities including provision of space for logical expansion of higher priority areas, such as the passenger terminal area;
3. The development of each area in the airport should be planned to make efficient use of land, and, in turn, the efficiency of use should be monitored on a continuing basis; and
4. If the supply of airport land is then exhausted as demands increase, the landside capacity could be increased by borrowing or acquiring off-site land for the lower priority uses, e.g., passenger processing facilities, warehouses, and parking.

This fourth step in the evolution of metropolitan airport facilities could indeed lead us to identify new and more effective types of integrated airport access and landside operations for serving the public.

MEASURING CAPACITY

Landside capacity begins with the capacity of the individual processing unit. Theoretically, the annual capacity of each processing unit could be expressed as its hourly throughput rate multiplied by the number of hours in the year. Obviously, this type of measure is meaningless because it bears no relation to the demand. Thus, an important distinction must be made between nominal (or rated) capacity and the practical flow rate that can be achieved.

The nominal capacity is the amount of demand (traffic) the facility can handle if there is a continual flow. Thus, for example, a highway lane that can handle a maximum of 2000 cars/h has a nominal capacity of 24 times 2000 or 48 000 cars/day.

Traffic during the night, however, is light. Thus, if the peak evening traffic is 2000 cars/h, the night traffic may perhaps be only 200 cars/h and the total number of cars passing through the lane per day may not be more than 30 000.

To move 48 000 cars through the lane in a 24-hour day is, of course, theoretically possible. This would mean that some cars would have to wait in a queue from the evening rush hour to the small hours of the morning. This is not practical, for the level of service is far too low to be acceptable.

This example indicates the derivation of the practical flow rate. It is quite obvious from the example that, whereas nominal capacity can be measured and expressed in simple technical terms (2000 cars/h), the practical flow rate is a function of the demand pattern and the service level.

With a service level of many hours of queuing for a substantial percentage of the traffic, the highway lane can handle 48 000 cars/day. If queuing is limited to, say, 1/2 h for not more than 10 percent of the cars, the practical flow rate would be reduced to perhaps 1300 cars/h and 35 000/day. If a higher service level is chosen, the practical flow rate would be even lower.

If we take this line of reasoning one step farther, we can, in turn, define achievable flow rates for individual processors. This achievable flow rate depends on the nominal (or rated) capacity, the pattern of demand, and the service level that is to be provided, taking into account the benefits and costs.

The service level must be expressed in terms of percentage of demand subject to more than a specific amount of delay or in some other similar manner. This percentage will primarily depend on the variation of momentary demand from one hour to another or from one day to another (weekday-weekend effect) or from one season to another.
The practical flow rate is often substantially lower than the nominal capacity because of the low demand during certain periods when the facility must be underused. The same road, baggage claim device, check-in scale, or other feature has a substantially different practical flow rate at different airports depending on the demand pattern. Thus, at New York (La Guardia) Airport, where the demand is almost even throughout the day, the practical flow rate of the same items is much greater than at Washington (Dulles) Airport, where the traffic pattern peaks. This means that the same item can handle many more people, cars, and so on during the day at La Guardia than at Dulles.

Similarly, the definition of achievable flow rate (the practical flow rate modified to the extent that acceptable levels of service can be provided to users) adds one more dimension to the measurement of landside capacity. Given these factors, the measurement of capacity involves constant monitoring and experimentation with respect to (a) the levels of service that are acceptable and economically justifiable and (b) the extent to which demand profiles can be altered to make greater use of the facilities during off-peak periods.

In addition to achievable flow rate, the holding capacity of facilities is also relevant to the measurement of landside capacity. For example, a short-term parking facility has a vastly higher capacity than a long-term parking facility, even though the achievable flow rate at the exits and entrances to the facility may be coincidentally the same. Thus, the accumulation of people, bags, vehicles, and packages becomes an important aspect in the measurement and definition of landside capacity.

A number of measures, such as differential pricing and the introduction of new services, can be considered for increasing the achievable flow rate of facilities. For example, the volumes of automobile traffic to and from an airport could be influenced by introducing high parking rates. A complementary measure would be to introduce high-quality bus services for passengers or employees or both to compete with the automobile modes of access to the airport. The combination of both of these measures could increase the achievable flow rate of the airport access system measured in terms of passengers.

Another approach would be to encourage employers at the airport to promote staggered work hours. Although certain types of employees are tied to airline schedules, some employee commuting trips could be diverted to off-peak hours by introducing flexible or staggered hours. This change in the profile of demand will also result in an increase in achievable flow rate.

METHODOLOGIES FOR MEASURING CAPACITY

The measurement of landside capacity for an airport requires that we determine levels of demand for the essential movements of deplaning and enplaning, superimpose a demand profile on the nominal capacity at each level of consideration, and thus develop achievable flow rates at various ranges in level of service. This capacity determination, which represents the supply side of the equation, is applied in ascending order to each of the levels of consideration, commencing with the basic constraint at level 6—the aircraft door. Several methodologies have been developed to perform a number of functions in the estimation of airport landside capacity, and the detailed planning of passenger areas as well as the entire terminal complex. These are demand profile forecast, runway-taxiway simulation, accumulation models, and airport access model.

Demand Profile

One of the basic factors in defining achievable flow rates is the demand profile, which indicates the expected variation in demand for airport facilities by time of day as well as day of year.

The key factor in identifying the demand profile is the schedule of aircraft movements. The pattern of aircraft movement is directly related to the role of the airport and the type of traffic that is served. For example, the new airports at Toronto and
Montreal will exhibit relatively high peaks because aircraft schedules must be related to time zones, flight times, and curfews at European airports. By comparison, a purely domestic airport or an airport serving international traffic oriented in a north-south direction (e.g., Miami) would exhibit less peaking and potentially greater uniformity of demand throughout the day.

The subject of demand forecasting could be the topic of a special conference in itself. However, for the purposes of this paper, I would like to confine my remarks to identifying 4 basic approaches to developing the demand profile: simple judgment, trend projections, econometric or mathematical models, and market method. This listing is in the order of increasing complexity. Usually each of these basic methods includes some element of the other methods above it. Thus, for example, the market method will contain elements of judgment, trend projections, and mathematical models.

1. Simple judgment is not really a method, but in many cases it produces surprisingly good results.

2. Trend projections are based on a simple continuation of past experience in the quantity that has to be forecast. Thus, if we wish to forecast the number of domestic air trips, we would look at the number of domestic air trips during the past, say, 10 years, plot them on graph paper, observe their trend, and continue it into the future. The most convenient method of preparing trend projections is to choose a special scale on which the past trend is close to a straight line. In that case, the straight line can simply be continued.

   The main advantage of trend projections is that they are relatively simple and can be carried out fairly quickly. However, their disadvantage lies in their inability to offer any explanation for the growth, and therefore the uncertainty that past trends will continue is relatively high. In the absence of any insight into the reasons for the growth, to make an intelligent judgment regarding the possible future is difficult. Nevertheless, trend projections are useful for short-term forecasting (in the order of 5 to 10 years), since, in general, human behavior does not change suddenly and, even if trends might change as a result of the changing environment, this would take a substantial amount of time.

3. Econometric or mathematical models relate the change of the quantity that has to be forecast to a change in some other quantity. A model may relate, for example, the change in the number of international air travelers to a change in average personal income. It is, of course, still necessary to forecast the other variable, in this case, personal income. However, the reliability is greater of forecasting certain quantities than of forecasting others; it is, therefore, better to forecast the more reliable quantity first and then derive the desired quantity from that through a model.

   Mathematical models are superior to simple trend projections, especially for longer range forecasting. Their disadvantage lies in the limitation imposed by computational techniques: The form of the equation must be of such a nature that can be handled by mathematical methods. However, real life does not always produce such forms of equations, and it is necessary to compromise and accept a somewhat larger margin of error in the interest of being able to compute the relation. Another disadvantage is that all the quantities have to be expressed numerically in the mathematical equations. Important characteristics such as place of birth or education cannot normally be expressed in the form of numbers. For this reason, models are usually restricted to economic variables, such as income, gross national product, transportation costs, population, and distance. Because they deal mostly with numeric economic quantities, these forecasting models are often termed econometric models.

4. The market method provides the most insight into the behavior of people and their reasons for traveling. (It is also used widely for predicting purchasing habits and thus sales volumes of goods; hence, its name, market method). This method does not use complex mathematical equations. The population is divided into specific groups, according to characteristics such as income, place of birth, general area of residence, age, education, and occupation. It is then observed that, according to the group in which a person belongs (as defined by these characteristics), that person will, on the average, make a certain number of trips, buy a certain amount of a certain merchandise,
and so on. The assumption is made that, once a person belongs to a particular group as described by those characteristics, he or she will behave like other people who belong to that group. As time goes on, people will move from one group to the other (reflecting their changes in age, education, income). As they move from one group to another, so their habits will change; and, once they move into a new group, they will take up the habits of others in that group.

The market method thus transforms the forecasting of air travel into the forecasting of the number of people in the various socioeconomic groups. The forecasting of the number of people in these groups is quite reliable since, for example, the age of air travelers can be predicted with a high degree of accuracy; most travelers are adults and most of those traveling in the next 25 years are already alive. Similar reliability can be attached to other socioeconomic variables, such as income, for instance.

The disadvantage of the market method is that it requires a thorough survey of the population in order to determine the habits of the various socioeconomic groups. The greater the number is of characteristics considered, the greater the number will be of groups. And since every group in a surveyed sample of the population must contain a fair number of people to provide an acceptable level of reliability, the size of the required survey sample could become large.

As a result, the costs of the market method and the time required to apply it are considerably greater than those of the other methods. On the other hand, however, the market method is probably the most reliable forecasting method for long-range planning. It provides the greatest insight into the reasons for the growth of the quantity to be forecast, for it relates the forecast to human behavior and habits that are easily understood and to which judgment may be easily applied.

Because of the implications associated with the acquisition of a new airport site and the need to provide accurate information to the public, the market method was selected as appropriate for the long-range planning of the Toronto area airport system. The air traffic in Toronto is fairly significant, exceeding 10 million enplaning and deplaning passengers; according to the latest statistics, Toronto is the thirteenth air traffic hub of the world.

The use of the market method provided a reasonably reliable indication of the types of passengers who would use each airport in the system and the characteristics associated with these types of passengers, e.g., number of bags, access mode, and number of well-wishers and greeters. These types of characteristics are fundamental to the measurement and estimation of landside capacity.

Runway-Taxiway Capacity

A number of methodologies have been developed for simulating runway and taxiway capacities. This paper addresses landside capacity, but it is worthwhile noting that companion methodologies are available for examining airside capacities.

Gate-Processor Models

If there is a steady flow of traffic, a simple comparison of the ideal or nominal capacities with the traffic demand is usually sufficient to determine the number of processors that are required. If, however, there are significant gaps between successive uses of a facility (such as an aircraft parking position or baggage claim device), more sophisticated methods must be used since any idle time during which the processor cannot function because of a temporary lack of demand decreases its capacity. The decreased capacity determines the practical flow rate that the element can handle. As discussed earlier, the achievable flow rate is the practical flow rate associated with the level of service that will be accepted by the user of the facility. These flow rates can be determined by various methods; simulation models are particularly suited for the purpose.

We have developed such a simulation model and used it widely in airport planning
projects. The model simulates many days of traffic and varies arrival or departure of aircraft randomly within certain limits around a specified average 6-hour schedule. For each day, it calculates the percentage of passengers who would be delayed given a certain number of gates and processors as well as the average amount of delay in minutes experienced by delayed passengers.

This model makes it possible to determine delays in the system for a range of alternatives. If a social or economic cost can be associated with the delays of air travelers, trade-offs can be established between the cost of facilities in the various alternatives and the cost of delays. Thus, an optimum can be found.

The assignment of a cost to people's time is usually a vague task. Fortunately, in most instances, the results of an optimization process of the kind described are not sensitive to the cost of time and will indicate the same optimum for a fairly wide range of costs.

Figures 7 and 8 show the optimization of the number of aircraft gate positions for the new Montreal international airport. Given a forecast aircraft schedule, aircraft and passenger delays were computed with the simulation for 19, 20, 21, 22, 23, and 24 gates and for the length of the delay. Figure 7 shows the actual annual cost of delays to the airlines, the assumed trade-off cost to the passenger, and the annual cost of providing more gates. As the cost of gates increases, the delays in their associated costs decrease. The minimum total cost is at 20 gates in this example. Figure 8 is similar to Figure 7 except that the trade-off value of a passenger delay was assumed to be $15 rather than $2. In this case the minimum total cost is at 22 gates.

Accumulation Models

Since the landside capacity of an airport is a function of both achievable flow rates by processor and the holding capacities of these processors, the dwell times of people, vehicles, and baggage are basic parameters in establishing the capacity of a facility. For this reason, we developed a peak flow model for Toronto area airports in order to estimate the accumulation of people, vehicles, and bags through the enplaning and deplaning processing sequences.

Airport Access Model

In terms of estimating airport access travel demands and modal split, a number of conventional urban transportation models are available. Although these models can be adopted to estimate demands for ground transportation, they are heavily oriented toward travel habits based on past observations and, hence, tend to reflect historic propensities for automobile travel.

Given the possibility of assigning some airport functions, such as passenger processing, to off-site locations, the use of conventional transportation modeling techniques is open to question, particularly if there is a constraint on available road capacity. In such cases, behavioral models such as LOGIT could be more relevant. Also, more up-to-date empirical evidence is necessary to assess the effects and public reaction to different types of off-site services. A series of carefully planned demonstration projects could be an ideal way to obtain empirical evidence for estimating possible requirements and demand for ground transportation facilities. Indeed, constant testing, monitoring, and experimentation are appropriate to improving the capacities of existing facilities and to understanding the achievable capacities of new facilities in the future.

SUMMARY

We identified 6 basic levels of consideration: metropolitan airport system, each airport and its environs, airport and its basic elements, functions of each airport element, processing facilities for each function, and each processing facility. We noted that
Figure 7. Annual cost of gates and ramp delays for passenger delay value of $2.

Figure 8. Annual cost of gates and ramp delays for passenger delay value of $15.
demands are established by the decisions that are taken from level 1 down through level 6 but that the supply or capacity of facilities is established in the reverse order.

Landside capacity is becoming more critical than airside capacity since individual runway capacities increase with larger aircraft and improved airside control systems, creating corresponding increases in landside demand.

Effective use of land, particularly land with access to the runways, is a prime objective at most mature airports. As the landside constraints begin to operate at existing airports, the need arises to assign priorities to each airport function in terms of access to runways. Lower priority uses are assigned to remote sections of the airfield and higher priority uses expand into the vacated land areas near the runways.

A natural evolution is for some uses to be located outside the airport in off-site locations. In fact, this approach provides a means of expanding the airport land area.

Land is the fundamental factor in establishing the landside capacity and, indeed, the total capacity of the airport. In the planning of new airports, more land should be acquired than is estimated to be required during the foreseeable future. At all airports, the planning should focus on the efficient use of land and the potential for using off-site lands for certain functions that do not require access to the runways.

The key factors in assessing capacity include the achievable flow rate, defined as the practical flow rate of a system associated with a level of service that is acceptable to the user and is economically justifiable, and dwell times that reflect the holding capacities required at each processor.

Finally, we described a number of methodologies for estimating demand profiles, optimizing facilities requirements, estimating accumulations, particularly during peak periods, and estimating airport access demands. A continuing program for monitoring the performance of facilities and for obtaining empirical evidence on public acceptance of various types of service is necessary, particularly in relation to ground access and the potential future role of off-site airport facilities.

The application of these principles in planning for new airports or in evaluating land use at existing airport sites enables meaningful comparisons to be made among airports since we are able to determine a cost to achieve a flow rate within certain levels of service by category of passenger expected to use the airport facility.